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PROJECTILE MOTION AND LOADS VERSUS TRAVEL IN GUN TUBE

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MATERIALS APPLICATION DIVISION

March 1977

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ABSTRACT

Using a Le Duc representation of the pressure-travel curve, the linear and angular velocity and acceleration of the projectile are determined as a function of travel within the gun tube. With the motion parameters established, the set-back force, spin force, and spin moment are calculated as a function of travel within the gun tube.

Based on these equations a computer program is developed which outputs, both graphically and in tabular form, the force, moment, and motion parameters for the projectile during the interior ballistic regime. The program requires the input of the projectile weight, diameter, polar moment of inertia, muzzle velocity, gun length, maximum pressure, location of maximum pressure, and the rifling twist. A FORTRAN listing of the program is given and the program illustrated by a sample problem.

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CONTENTS

Page

INTRODUCTION. 1

OBJECT. 1

RIFLING 1

Profile. 2

Twist. 2

PROJECTILE MOTION IN GUN TUBE 4

Velocity 4

Acceleration 5

FORCES AND MOMENTS ON PROJECTILE IN GUN TUBE. 6

Axial Force. 6

Spin Moment. 8

Spin Force 8

RESULTS AND DISCUSSION

Rifling. 10

Projectile-Gun Parameters. 11

Pressure and Velocity versus Travel in Gun Tube. 12

Projectile Motion. 12

Forces 14

Spin Moment. 15

REMARKS 16

APPENDIX A. FORTRAN LISTING OF COMPUTER PROGRAM FOR PROJECTILE LOADS IN GUN TUBE 17

APPENDIX B. PROJECTILE MOTION AND LOADS VERSUS TRAVEL IN GUN TUBE. . 25

INTRODUCTION

Currently, improvements in projectile design are concerned with the use of thinner shell wall components in the round itself and the replacement of conventional copper rotating bands by those which use a less critical material. Before changes of this nature can be adopted, it must be guaranteed that the projectile will maintain its structural integrity under the severe stress patterns developed by the loading during the launch cycle. Under these circumstances, it is required that the impressed loads be determined with detailed accuracy throughout the launch cycle.

For most projectile-gun systems, pressure and velocity travel curves are available for a range of muzzle velocities. With this information the linear and angular acceleration of the projectile are readily derived. Once the accelerations are established, the magnitude of the critical forces and moments acting on the round may be deduced as a function of travel within the gun tube.

The most important forces imposed on the round are the axial or set-back force and the spin-producing force which acts at the interface of the rifling and rotating band. This force develops the spin necessary to stabilize the round and determines the acceptable rotating band materials and configurations. The set-back force causes axial compressive stresses to act along the shell body. Thus, the set-back force limits and establishes the acceptable shell body materials and dimensions.

In this report, the equations which express the pressure and the resulting axial force, spin force, and rotational torque on the projectile, as well as the linear and angular velocities and accelerations of the projectile are presented in some detail as a function of travel in the tube. The resulting equations are then applied to determine these parameters for a projectile-gun system for which pressure and velocity travel curves are available.

OBJECT

1. To assemble and present in sufficient detail equations which define the loads imposed on a projectile and the projectile's resulting motion during the interior ballistic cycle.

2. To develop a simple computer program which will print and plot the forces and resulting motion of a projectile during the interior ballistic regime.

RIFLING

During firing,[1] the rifling in the gun tube interacts with the rotating band of the projectile in order to provide spin. The projectile spin must be sufficient to resist the overturning aerodynamic moment developed on the round during free flight and maintain stability of the round.

1. Army Materiel Development and Readiness Command, Engineering Design Handbook, AMCP 706-252, February 1964.

Profile

Because the rotating band material is relatively soft, the lands engraved on the band must be sufficiently wide to maintain the band's structural integrity while transmitting the spin-producing torque. As a result, the rifling grooves must be wider than the lands.

It has been found empirically that a groove-to-land width ratio of 3/2 for the rifling will, in general, give satisfactory performance, thus

$$W_G = 1.5\ W_L \tag{1}$$

where W_G = groove width of rifling
W_L = land width of rifling.

In addition, it has been established that approximately eight grooves per inch of gun diameter are adequate, or

$$N_G \approx 8\ D \tag{2}$$

where N_G = number of grooves (to nearest whole number)
D = gun diameter (inches).

From Equations 1 and 2, the widths of the lands and grooves may be determined, thus considering the interior circumference of the tube

$$\pi D = N_G\ (W_G + W_L). \tag{3}$$

Substituting Equations 2 and 1 into the above

$$W_G = 0.2356 \text{ inch}$$

and $$W_L = 0.1571 \text{ inch.}$$

Empirically the depth of the rifling groove has been determined as

$$h = 0.01\ D \tag{4}$$

where h = rifling groove depth (inches).

From the above equations a general rifling configurations is readily calculated for any diameter gun.

Twist

Twist is of paramount importance because it is directly related to free flight stability. In general, a gun tube can provide either a constant or an increasing twist. The equation for the rifling curve is

$$y = px^n \tag{5}$$

and $$y = R\theta \tag{6}$$

where y = peripheral distance along rifling
p = constant
x = axial length along the gun tube
n = exponent which defines the rifling curve
R = radius of gun tube
θ = angular location along rifling.

The constant p is determined as follows

$$dy/dx = \tan\alpha = npx^{n-1}. \tag{7}$$

Now at the muzzle

$$x = L$$

and $\tan\alpha = \tan\alpha_E$.

Substituting this into Equation 7 gives

$$p = \tan\alpha_E/nL^{n-1}. \tag{8}$$

Substituting Equation 8 into 5

$$y = \left(\tan\alpha_E/nL^{n-1}\right) x^n. \tag{9}$$

For constant twist rifling n = 1 and (8) and (9) become

$$p = \tan\alpha \tag{10}$$

and $$y = (\tan\alpha)\ x \tag{11}$$

where α is now everywhere constant.

For constant twist rifling, the twist is usually specified as the number of projectile diameters (calibers) the projectile must move along the gun tube axis in order to complete one revolution, i.e., N_T calibers/turn.

Using this information in conjuction with (6) and (11), and

$$y = \pi D = \tan\alpha \times N_T(\text{cal/turn}) \times 1(\text{turn}) \times D(\text{in./cal})$$

and $$\tan\alpha = (\pi/N_T). \tag{12}$$

PROJECTILE MOTION IN GUN TUBE[1,2]

During firing, the pressure developed by the expansion of the propellant gas drives the projectile down the gun tube. During its passage through the tube, the projectile's rotating band engages the rifling of the tube and imparts an angular motion of the projectile about its axis of symmetry. The forward and rotational motion of the projectile are of major concern. These motions establish the two critical elements essential for satisfactory exterior ballistic performance, namely, muzzle velocity and projectile stability. Also, when the motions are delineated, the forces and moments acting on the projectile are readily reconstructed and the projectile can be efficiently designed to maintain its structural integrity throughout the launch cycle.

Velocity

The linear velocity of the projectile during its passage in the gun tube is usually measured at discrete intervals along the tube and for a range of muzzle velocities. This data is then presented in graphical form. With this information the linear and angular velocities and associated accelerations are readily represented in mathematical form.

a. Linear

It has been found that the velocity-travel curve is accurately reproduced by means of the Le Duc formulation in which the instantaneous velocity is assumed to be a hyperbolic function of the distance travelled in the tube, thus

$$V = ax/(b+x) \tag{13}$$

where V = instantaneous velocity
x = distance travelled in the tube
a,b = empirical constants.

b. Angular

The angular velocity of the projectile about its axis of symmetry is calculated from the equations which define the rifling curve and the linear velocity, thus

$$y = R\theta \tag{6}$$

and $$\frac{dy}{dx} = \tan\alpha = R\,\frac{d\theta}{dx} = R\left(\frac{d\theta}{dt}\right)\left(\frac{dt}{dx}\right)$$

$$\tan\alpha = R\dot{\theta}/V$$

and the angular velocity is

$$\dot{\theta} = V\,\tan\alpha/R. \tag{14}$$

2. HAYES, T. J. *Elements of Ordance.* John Wiley & Sons, Inc., New York, 1938.

Substituting (13) into (14) gives

$$\dot{\theta} = (\tan\alpha/R)\ (ax/b+x) \tag{15}$$

where $\dot{\theta} = d\theta/dt$ = instantaneous angular velocity of the projectile.

Acceleration

a. Linear

The linear acceleration follows directly from the linear velocity as expressed in (13), thus

$$\frac{dV}{dt} = \frac{(b+x)\ a\ dx/dt - ax\ dx/dt}{(b+x)^2}$$

and simplifying gives

$$a_c = dV/dt = \left(ab/(b+x)^2\right) V.$$

Substituting (13) into the above,

$$a_c = a^2\ bx/(b+x)^3 \tag{16}$$

where a_c = linear acceleration of the projectile.

b. Angular

In a similar fashion the angular acceleration is obtained from the angular velocity, thus, differentiating (15)

$$\ddot{\theta} = \frac{d\dot{\theta}}{dt} = \frac{1}{R}\frac{d}{dt}\ (V\ \tan\alpha) = \frac{1}{R}\frac{d}{dt}\left[\left(\frac{dx}{dt}\right)\left(\frac{dy}{dx}\right)\right]$$

and $$\ddot{\theta} = \frac{1}{R}\left[\frac{d^2x}{dt^2}\frac{dy}{dx} + \frac{dx}{dt}\frac{d}{dt}\left(\frac{dy}{dx}\right)\right]$$

$$\ddot{\theta} = \frac{1}{R}\left[\left(\frac{d^2x}{dt^2}\right)\left(\frac{dy}{dx}\right) + \left(\frac{dx}{dt}\right)\left(\frac{d^2y}{dt\ dx}\right)\left(\frac{dt}{dx}\right)\left(\frac{dx}{dt}\right)\right]$$

$$\ddot{\theta} = \frac{1}{R}\left[\left(\frac{d^2x}{dt^2}\right)\left(\frac{dy}{dx}\right) + \left(\frac{dx}{dt}\right)^2\left(\frac{d^2y}{dx^2}\right)\right]$$

which finally gives

$$\ddot{\theta} = \frac{1}{R}\left[a_c\ \tan\alpha + V^2\ \frac{d(\tan\alpha)}{dx}\right]. \tag{17}$$

For the case where the rifling twist is constant

$$\frac{d \tan\alpha}{dx} = 0$$

and (17) reduces to

$$\ddot{\theta} = a_c/(R \tan\alpha). \tag{18}$$

Substituting (12) and (16) into (18), the angular acceleration is expressed as a function of the rifling twist and the distance travelled within the gun tube.

$$\ddot{\theta} = \frac{a^2 bx}{(b+x)^3}\left(\frac{1}{R}\right)\left(\frac{\pi}{N_T}\right) \tag{19}$$

FORCES AND MOMENTS ON PROJECTILE IN GUN TUBE

The expanding propellant gas acting at the base of the projectile drives the projectile forward and at the same time spins it about its axis of symmetry. The spin is produced by the force system created by the interaction of the lands of the rotating band with the rifling grooves of the gun.

Pressure and velocity data are measured at intervals along the length of the tube during firing. The pressure and velocity data are usually presented in graphical form and are readily available for most projectile-gun systems. The measured pressure is utilized in overcoming friction and in imparting linear and angular acceleration to the projectile.

This information, in conjunction with the rifling curve and the projectile parameters, permits the calculation of the forces and moments acting on the projectile at any point in the gun tube.

Because it is less cumbersome algebraically and most convenient to develop all the forces and moments from the velocity travel curve, this procedure will be adopted in this report.

Axial Force

The axial force is coincident with the axis of symmetry of the projectile and results in the forward acceleration of the round.

For this determination, it is convenient to derive a forward velocity-producing pressure P_V from the hyperbolic velocity formulation. The magnitude of the pressure obtained in this fashion will everywhere be less than the actual measured pressure in the gun tube. This is so because the measured pressure produces the linear velocity and the projectile spin, overcomes friction in the tube, and accelerates the propellant gas and debris.

However, the velocity-producing pressure P_V follows the same general contour as the actual pressure P_G and differs from the actual pressure by a small multiplicative constant.

$$F_a = P_V A = M_p\, a_c \qquad (20)$$

and $$P_G = C_1\, P_V \qquad (21)$$

where F_a = axial force

P_V = pressure which produces linear velocity

A = base area of projectile

M_p = projectile weight

a_c = linear acceleration

P_G = measured pressure in gun tube

C_1 = empirical constant.

Substituting (16) into (20) gives

$$P_V = \frac{M_p\, a^2\, bx}{A\,(b+x)^3}\,. \qquad (22)$$

The measured pressure and axial force are obtained as a function of projectile travel from (20), (21), and (22), thus

$$F_a = \frac{M_p\, a^2\, bx}{(b+x)^3} \qquad (23)$$

$$P_G = C_1\, \frac{M_p\, a^2\, bx}{A\,(b+x)^3}\,. \qquad (24)$$

The distance along the gun tube at which the maximum pressure occurs is of critical concern. At this point the stresses in the gun and the projectile are both at a maximum.

This distance is determined by equating the first derivative of the pressure with respect to x equal to zero and solving the resulting equation for x. If this is done, it is found that

$$X^* = b/2 \qquad (25)$$

where X^* = distance along gun tube at which maximum pressure occurs

b = Le Duc constant.

The maximum pressures and forces developed in the gun tube are obtained by substituting (25) into (22), (23), and (24).

This gives

$$P_{V_{max}} = (4/27)(M_p/A)\, a^2/b \qquad (26)$$

$$F_{a_{max}} = (4/27)\, M_p\, a^2/b \tag{27}$$

$$P_{G_{max}} = 4\,(C_1/27)(M_p/A)\, a^2/b. \tag{28}$$

The constant C_1 follows from (26) and (28), thus

$$C_1 = P_{G_{max}} \big/ P_{V_{max}}. \tag{29}$$

Spin Moment

The torque which produces spin about the axis of symmetry of the projectile is given as

$$T = I_p\, \ddot{\theta} \tag{30}$$

where T = torque about axis of symmetry

I_p = polar moment of inertia of the projectile

$\ddot{\theta}$ = instantaneous angular acceleration.

Substituting the expression for the angular acceleration as given by (17) into (30),

$$T = (I_p/R)\,[a_c \tan\alpha + V^2\, d(\tan\alpha)/dx]. \tag{31}$$

If the twist α is constant, (31) reduces to

$$T = I_p\, a_c \tan\alpha/R. \tag{32}$$

The torque may be expressed as a function of the travel in the gun tube by substituting (12) and (16) into (32), thus

$$T = (I_p/R)\ (\pi/N_T) \left[\frac{a^2\, bx}{(b+x)^3}\right]. \tag{33}$$

Comparing (22), (23), and (33), it is seen that P_V, F_a, and T vary directly as a function of the linear acceleration. Because of this, plots of all three quantities will have the same general contour when expressed as a function of x. Also the maximum value of each of these quantities will occur at the same location defined by (25).

Spin Force

The forces which cause the projectile spin are developed through the interaction of the lands of the rotating band with the rifling grooves.

The forces resulting from this interaction are depicted in Figure 1 where it is seen that

$$F = N_R\,(\cos\alpha - \mu \sin\alpha) \tag{34}$$

or $\quad T = (N \cos\alpha) R (1 - \mu \tan\alpha)$ (35)

where N = normal force acting along the depth of the lands
μ = coefficient of friction between rifling and rotating band.

Now substituting (31) into (35),

$$N = \left(I_p/R^2\right) \frac{\left[a_c \tan\alpha + V^2 \frac{d(\tan\alpha)}{dx}\right]}{\cos\alpha\ (1 - \mu \tan\alpha)} . \tag{36}$$

For a constant twist rifling (36) becomes

$$N = \left(I_p/R^2\right) \frac{a_c \tan\alpha}{\cos\alpha\ (1 - \mu \tan\alpha)} . \tag{37}$$

This result may be further simplified by recalling that

$\mu < 1$

$\tan\alpha \ll 1$

therefore, $(1 - \mu \tan\alpha) \doteq 1$

with this approximation, (37) may be written

$$N = I_p\ a_c \tan\alpha/(R^2 \cos\alpha). \tag{38}$$

If (16) is substituted into (38), the spin force may be expressed as a function of the distance travelled in the tube, thus

$$N = I_p \tan\alpha\ a^2 bx/[R^2 \cos\alpha\ (b+x)^3]. \tag{39}$$

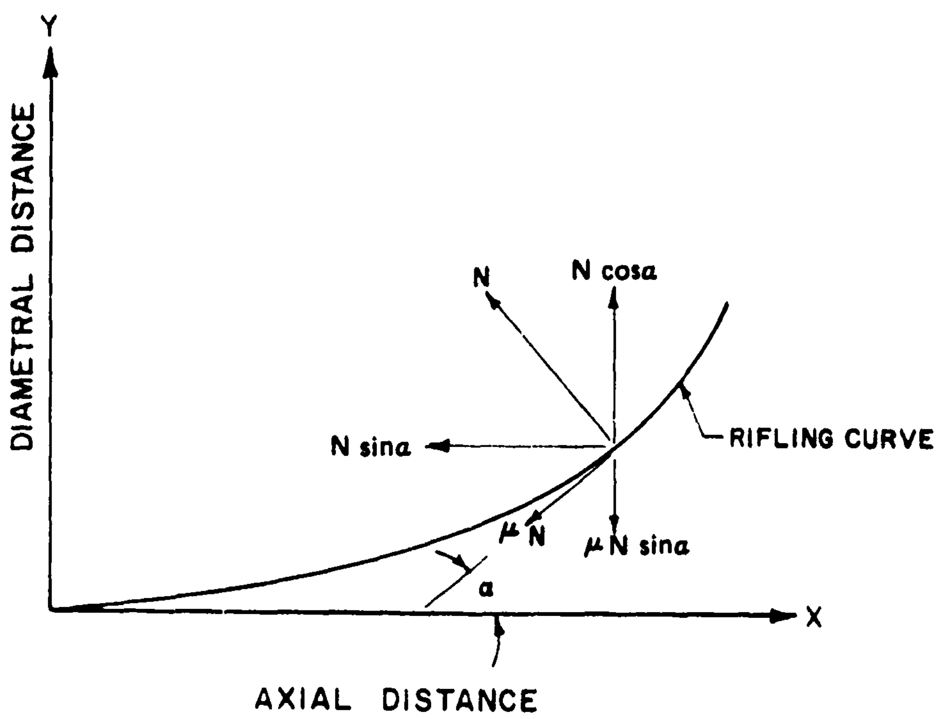

Figure 1. Force diagram due to interaction of rifling and rotating band.

RESULTS AND DISCUSSION

Rifling

A typical rifling profile for an artillery weapon is illustrated in Figure 2. Using (1), (2), and (4), the number, depth, and width of grooves for a typical artillery rifling configuration is plotted in Figure 3 as a function of the gun diameter. These figures detail a representative rifling profile. In practice, deviations from this norm are introduced for a variety of reasons. However, the initial design of a new artillery weapon usually starts with the typical profile and alters this result to conform with stringent mission requirements.

The rifling twist imparts spin to the projectile in order to provide gyroscopic stability to the projectile when it emerges from the muzzle. The spin must be sufficient for the projectile to resist the upsetting aerodynamic forces and moments developed in free flight and to cause the initial yawing motion induced at launch to damp out rapidly. To perform satisfactorily, the axis of symmetry of the projectile must be maintained in substantial alignment with the instantaneous tangent to the trajectory as the round proceeds to the target.

The rifling may develop the required projectile spin through either a constant or increasing twist. With an increasing twist, the final spin imparted to the round corresponds to the twist at the muzzle. An increasing twist is used primarily to reduce the peak maximum forces and moments developed in the tube during the launch cycle.

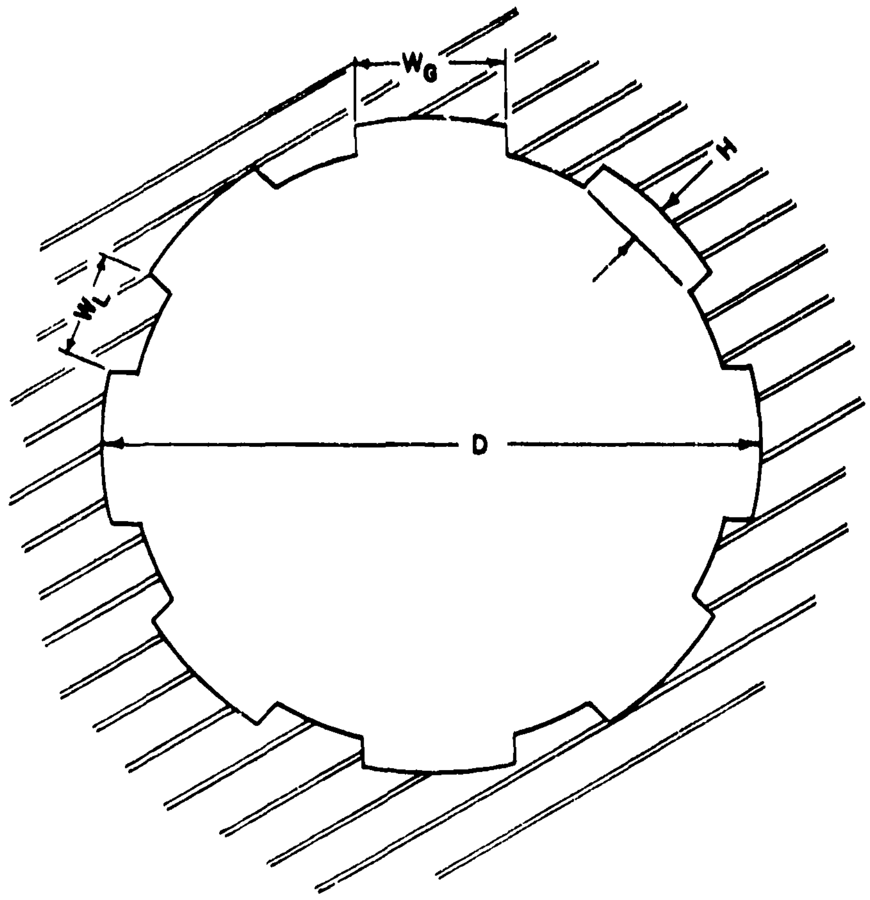

Figure 2. Typical rifling configuration.

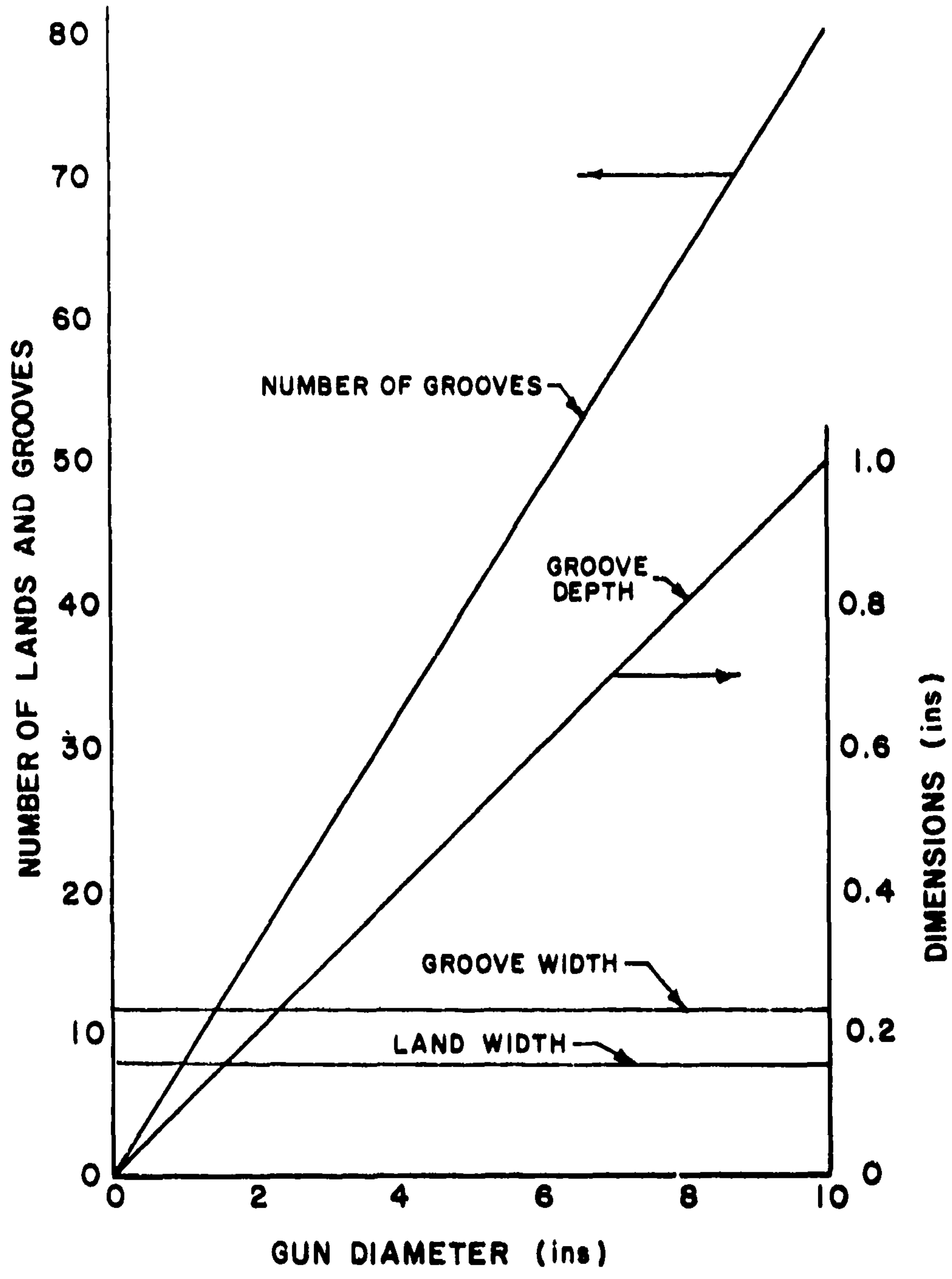

Figure 3. Dimensions and number of lands and grooves in typical rifling profile versus gun diameter.

Projectile-Gun Parameters

The equations presented herein are sufficiently general and apply to any artillery projectile-gun combination. However, in order to illustrate the variation of the force and motion parameters as a function of travel in the gun tube, specific projectile-gun parameters associated with conventional artillery shell will be assumed.

a. <u>Projectile</u>

Weight - 96.0 pounds
Diameter - 6.0 inches
Polar moment of inertia - 495 lb-in.^{2}

b. <u>Gun</u>

Caliber - 155 mm
Length - 200 inches
Twist - 20 cal/turn.

Of the many pressure and velocity travel curves available for the 155-mm artillery cannon, Zone 8 results will be used.

The following data is extracted from a representative curve

Muzzle velocity - 2,800 fps

$P_{G_{max}}$ - 53,900 psi

X* - 22.5 inches.

X* identifies the distance along the gun tube where the maximum pressure $P_{G_{max}}$ occurs. With X* known, the empirical constant b which appears in the Le Duc velocity formulation, Equation 3, is calculated through Equation 25. With b established, a is determined from (13) by noting that V = muzzle velocity (2800 fps) at X = gun length (200 inches). When the constant terms a and b in the velocity equation are known, the force and motion parameters are readily calculated.

The pertinent equations which describe the motion of the projectile and the forces and moments which produce that motion were programmed for the computer. The plotting routines available from the computer were used to develop the graphs presented in Figures 4 to 8. The FORTRAN listing for the complete program is given in Appendix A. The projectile-gun system parameters detailed above were used in performing the calculations. The gun-tube pressures, linear and angular velocities and accelerations, the axial and spin forces, and the torque are given as a function of travel in the gun tube in the table in Appendix B.

It is noted that for the constant twist rifling assumed here, all the important force and motion parameters except the linear and angular velocities are linearly dependent on the acceleration and thus the pressure. With the exception of the velocities, all the curves discussed below effect the same general contour as the pressure travel plot. The values at the start are zero, the maximum values are reached at X = X* and after this the values steadily decrease up to the muzzle. The linear and angular velocities are both hyperbolic functions and increase from zero at the start of travel to a maximum at the muzzle.

Pressure and Velocity versus Travel in Gun Tube

The pressure acting in the gun tube and the instantaneous velocity of the projectile as it travels down the gun are plotted in Figure 4 as a function of distance travelled in the tube. The velocity was calculated using (13), where the empirical constants were first calculated as described above. The measured gas pressure distribution in the gun tube is determined from (29), (22), and (21), where the value of $P_{G_{max}}$ has been read from the available curve.

Projectile Motion

a. Linear

The linear velocity and acceleration of the projectile are plotted as a function of the distance travelled in the gun tube in Figure 5. The linear velocity is derived from (13) while the acceleration follows from (16).

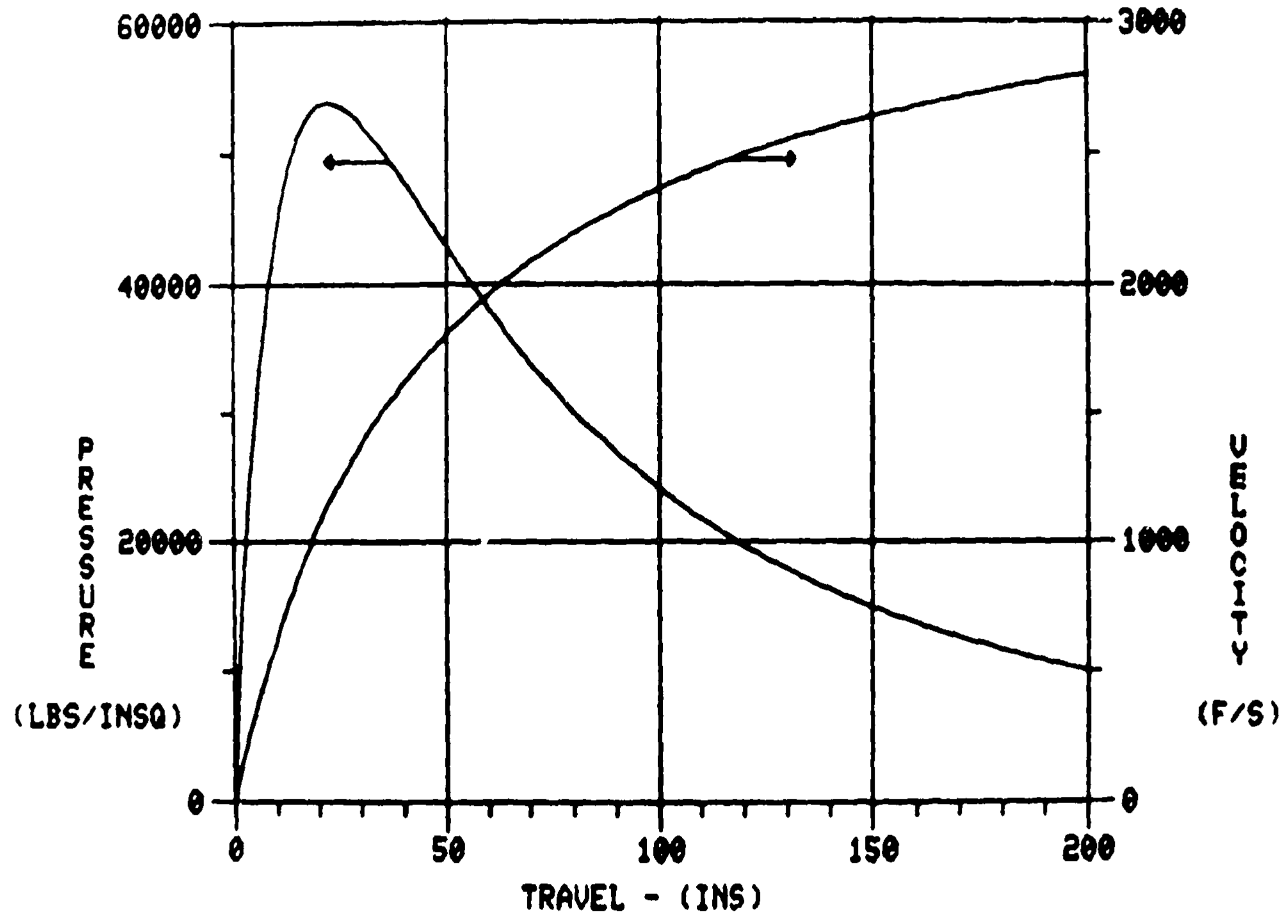

Figure 4. Pressure and velocity versus travel in gun tube.

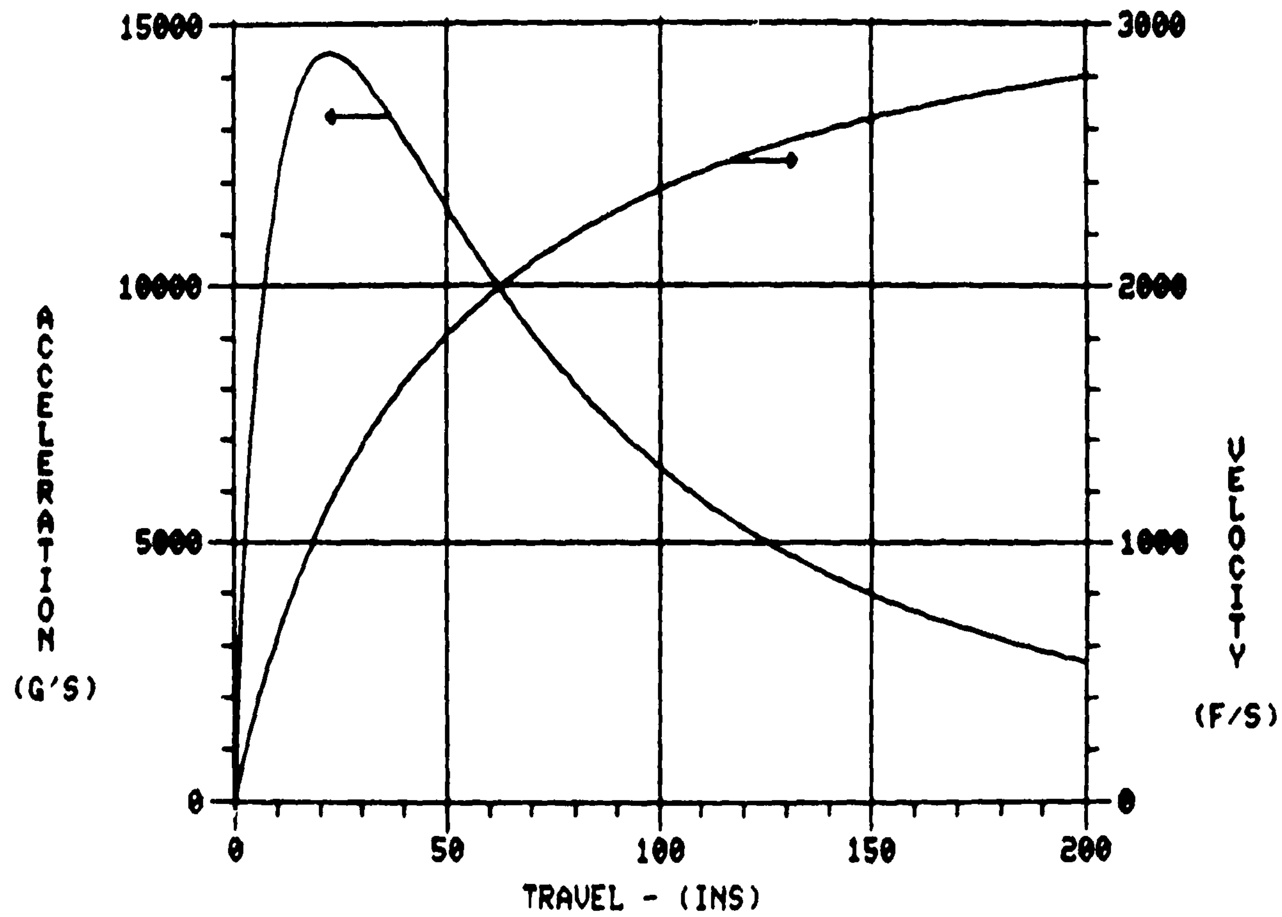

Figure 5. Linear velocity and acceleration versus travel in gun tube.

b. Angular

The angular velocity and acceleration of the projectile is plotted as a function of travel in the gun tube in Figure 6. The angular velocity which is linearly dependent on the translational velocity is calculated from (15), while the angular acceleration which is linearly dependent on the translational acceleration is determined from (19).

Forces

The axial and spin forces acting on the projectile are plotted in Figure 7 and are described by (23) and (39) as a function of the distance travelled in the gun tube. Both forces are linear functions of the acceleration and as a result have the same general contour differing only in magnitude.

The tangential force may be used to calculate the maximum stress distribution in the rotating band or adjacent projectile area. This result should prove especially useful in evaluating the performance of the new braze bonding method now being developed to attach rotating bands to artillery projectiles.

The plotted force is the maximum force developed at the base of the round. To determine the force applied at an intermediate interface of the projectile, the force obtained from the plot need only be multiplied by the ratio of the weight forward of the interface divided by the total round weight.

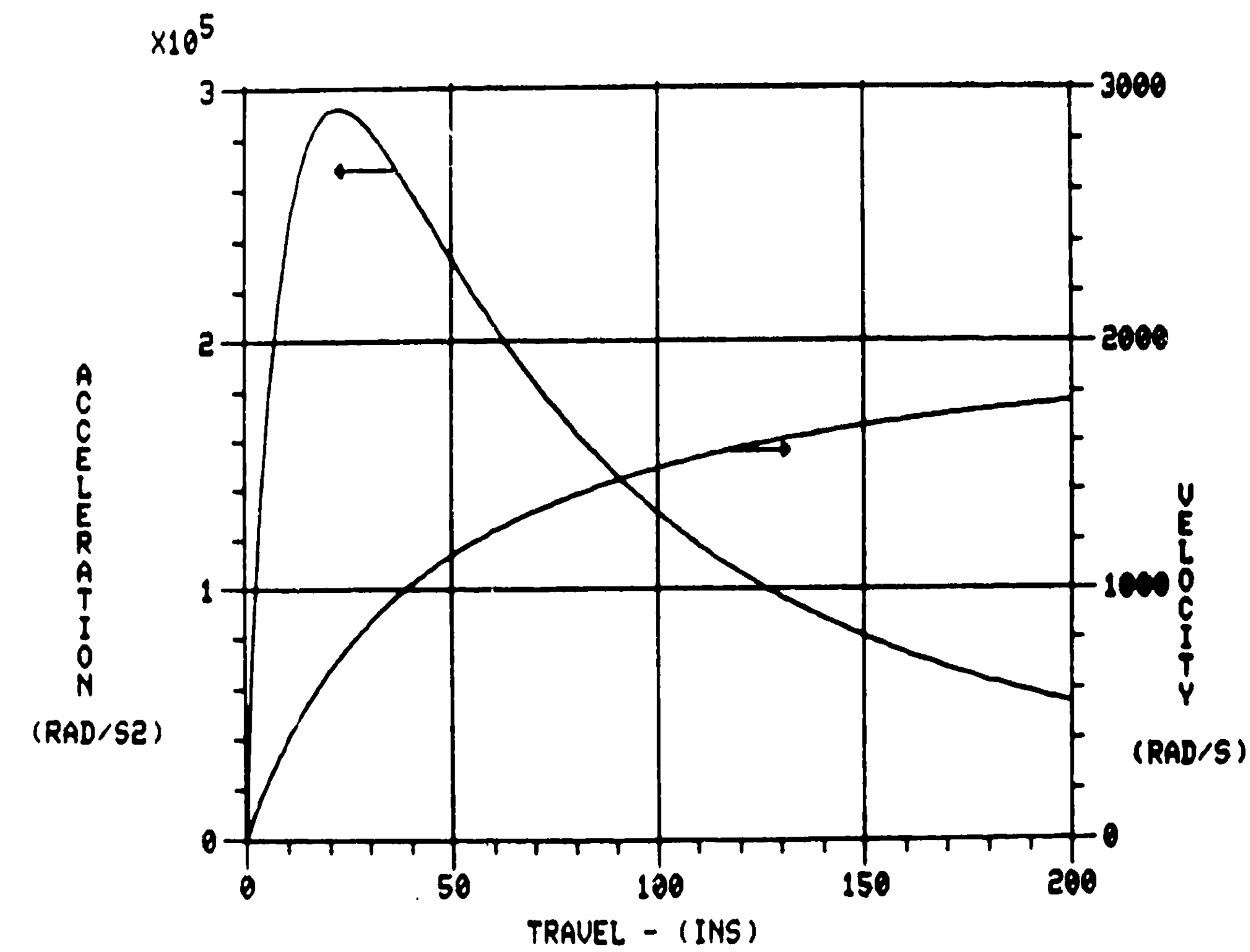

Figure 6. Angular velocity and acceleration versus travel in gun tube.

Spin Moment

The unbalanced moment acting about the axis of symmetry of the projectile which derives from the tangential force and produces the spin is calculated from (33). The result is plotted as a function of travel in the gun in Figure 8.

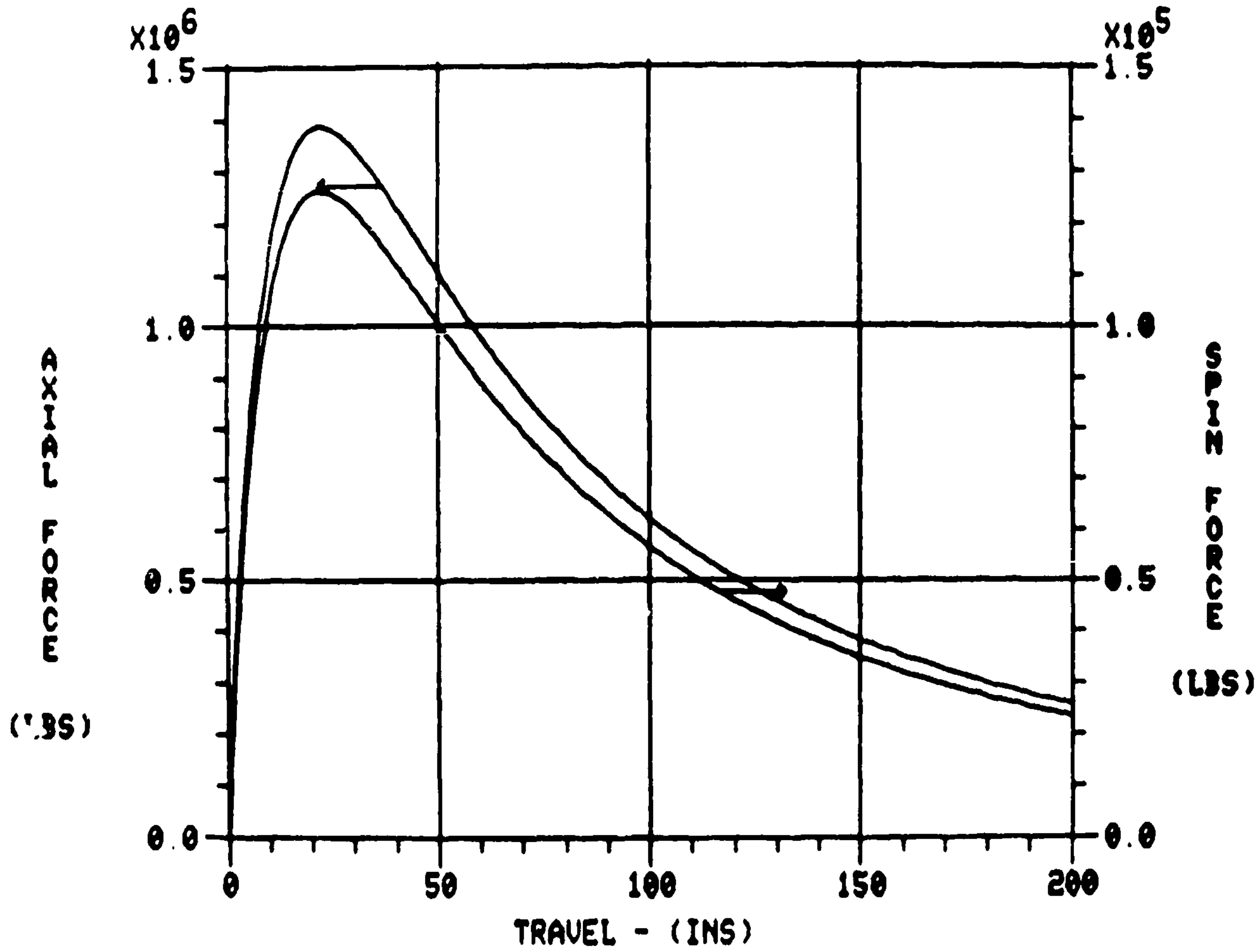

Figure 7. Axial and spin forces versus travel in gun tube.

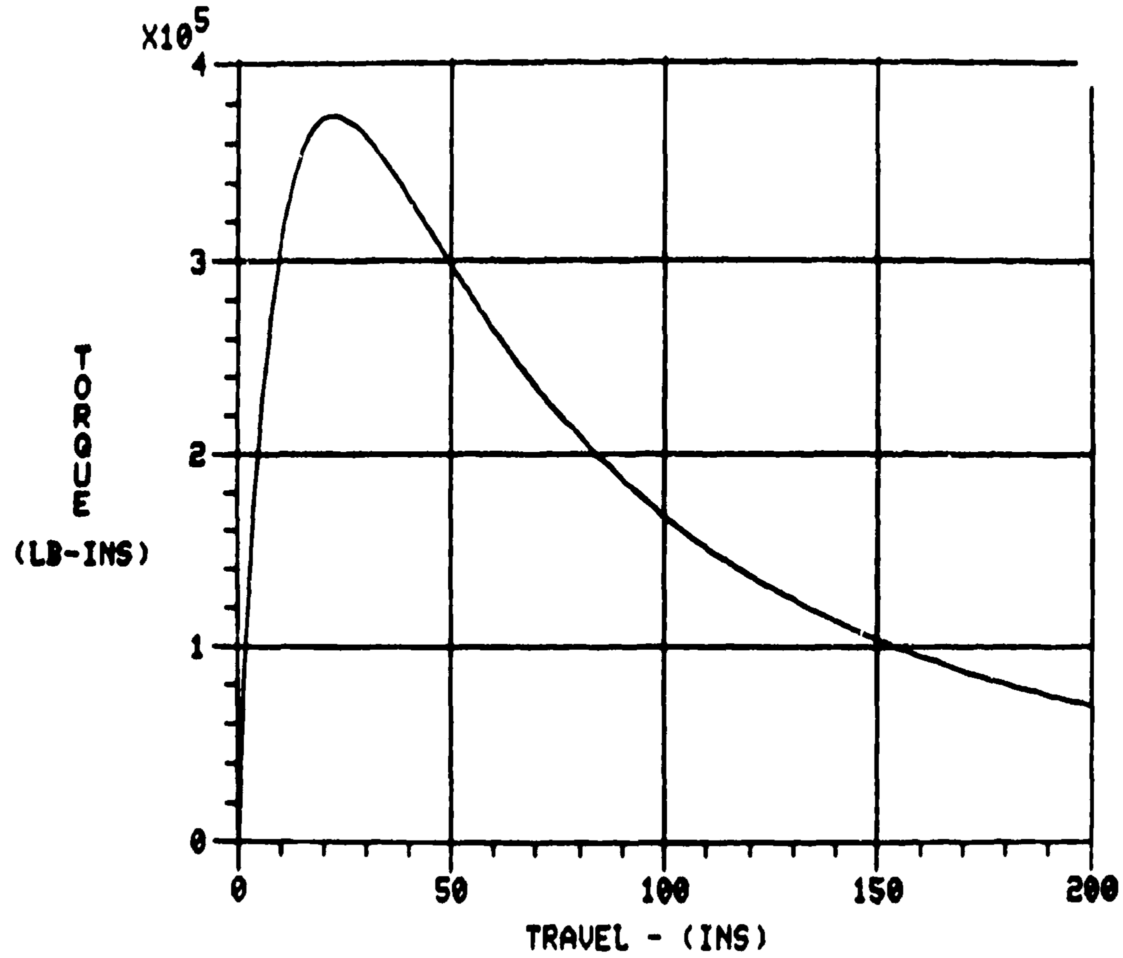

Figure 8. Torque versus travel in gun tube.

REMARKS

The computer program presented herein has been developed for constant twist rifling. At some later date it will be modified to include variable twist rifling. The modifications will include provisions for altering the variable rifling curve at its inception in order to minimize the initial stresses.

The procedures and program used to obtain the force and motion results for artillery projectiles launched from 155-mm cannon will be applied to all conventional projectile-cannon systems when the appropriate pressure and velocity travel curves are made available.

In this report, the analysis and equations that are presented and programmed have largely been extracted from the Engineering Design Handbook Series prepared by DARCOM. This series presents the analytical methods and the appropriate equations and procedures to be used in designing ordnance equipment. It would be advantageous if all major portions of the Handbook were computerized. The computer program should both print and plot all pertinent information necessary for the determination of the most efficient component design. The computer programs and computer manuals should be made available to all Army installations and major contractors charged with the responsibility of developing ordnance equipment. In this fashion, conventional, time-consuming hand calculations are eliminated, initial design concepts are rapidly evaluated, and the preliminary results widely disseminated and reviewed by responsible monitors.

APPENDIX A. FORTRAN LISTING OF COMPUTER PROGRAM FOR PROJECTILE LOADS IN GUN TUBE

```
MAIN  =====

            COMMON /CAFLOT/ PRESS(402),VEL(402), ACC(402),TH1D(402), TH2D(402)
           1 , FORCE(402), TORQUE(402),X(402), EN(402)
            REAL LGTH,IPOLAR
            DIMENSION HEDING(8)
      C
            G=32.2
            PI=3.1415927
      C
          2 CONTINUE
            WRITE (6,150)
        150 FORMAT( ' READ IN HEADING 48 CHARACTERS MAX ')
               READ (5,112)  (HEDING(L), L=1,8)
               CALL INITT(30)
               WRITE(6,101)
            READ (5,102)  WT, DIAM, LGTH, VMUZ, XMAX, PMAX, CALTUN,IPOLAR ,
           1 MORE
      C
            KOUNT=39
      C
            WRITE(7,107) WT,DIAM, IPOLAR, VMUZ
            WRITE (7,108) LGTH, PMAX, XMAX, CALTUN
          3 CONTINUE
      C
            TANALF=PI/CALTUN
            ANG=ATAN(TANALF)
            CSALFA=COS(ANG)
            AREA=0.25 *PI*DIAM**2
            B=2.* XMAX
            A=VMUZ*(B + LGTH)/LGTH
               WRITE (7,109)  A, B
      C
      C
            IF (IPOLAR .NE. 0.) GO TO 6
            IPOLAR = WT*(0.140*DIAM**2)
            WRITE (7,111) IPOLAR
          6 CONTINUE
      C
            IF(PMAX .EQ. 0.) FAC=1.
            IF(PMAX .EQ. 0.) GO TO 15
            PMAXC=48.*WT*(A**2) /(27.*AREA*G*B)
            FAC =PMAX/PMAXC
         15 CONTINUE
            COEFF=12.*FAC*WT/ (AREA*G)
      C
            ENDPT=LGTH + 0.5
            IEND= ENDPT
      C  INCREASE IEND IN ORDER TO INCLUDE ZERO POINT AND DATA STORAGE FOR
      C       PLOTTING
            IEND=IEND+2
      C
            DIS=-1.0
      C
      C CHECK TO SEE IF XMAX OCCURS IN THE STANDARD ONE INCH INCREMENTS
      C
            DO 40 I=1,IEND
            DIS=DIS + 1.
            IF(XMAX .NE. DIS ) GO TO 40
            ISTAR=0
            GO TO 50
         40 CONTINUE
```

```
MAIN  =====

      C
      C ARRIVES HERE IF THE VALUE OF XMAX IS NOT BETWEEN 0 AND LGTH IN INCREMENTS
      C   ISTAR=1 INDICATES THAT XMAX HAS FRACTIONAL VALUE
            ISTAR=1
      C
      C  INCREASE IEND IN ORDER TO INCLUDE  XMAX POINT
            IEND=IEND +1
         50 CONTINUE
      C
            IEN=IEND-1
            X(1)=IEN
            PRESS(1)=IEN
              VEL(1)=IEN
              ACC(1)=IEN
             TH1D(1)=IEN
             TH2D(1)=IEN
            FORCE(1)=IEN
            TORQUE(1)=IEN
            EN(1)=IEN
      C
      C
            DIS=-1.
            IFLAG=0
      C
            DO 10 I=2,IEND
            IF (IFLAG .EQ. 0) GO TO 8
            X(I) =XHOLD
            XM1=XMAX + 1.
            IFLAG=0
            GO TO 9
          8 CONTINUE
            DIS=DIS + 1.
            X(I)=DIS
            XHOLD=X(I)
            XM1= X(I)-1.
          9 CONTINUE
            IF ( X(I) .GT. XMAX .AND. XM1 .LT. XMAX ) IFLAG=1
            IF (IFLAG .EQ. 1) X(I)=XMAX
            IF (I .EQ. IEND) X(I)=LGTH
            BTERM=(B+X(I))
            VEL(I)=A*X(I)/BTERM
            PRESS(I) = COEFF * (A**2) *B*X(I)/ (BTERM **3)
            ACC(I)=12.*(A**2)*B*X(I)/(BTERM**3)
            TH1D(I)= 24.*VEL(I)* PI/( DIAM* CALTUN)
            TH2D(I)= 24.*ACC(I)* PI/ (DIAM* CALTUN)
            ACC(I)=ACC(I)/G
            FORCE(I)=WT*ACC(I)/1000.
            TORQUE(I)= 2.*IPOLAR*TANALF*ACC(I)/(DIAM*1000.)
            EN(I)=2.*TORQUE(I)/ (DIAM*CSALFA)
         10 CONTINUE
      C
            WRITE (7,114)  (HEDING(L), L=1,8)
            WRITE(7,104)
            LINES=0
      C
      C
            DO 20 K=2,IEND
            I=K
            LINES=LINES + 1
            WRITE (7,105)  X(I), PRESS(I), VEL(I), ACC(I),TH1D(I),TH2D(I),
           1 FORCE(I), TORQUE(I), EN(I)
```

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MAIN =====

```
      FORCE(I)=FORCE(I)*1000.
      TORQUE(I)=TORQUE(I)*1000.
      EN(I)=EN(I)*1000.
C
      IF(LINES .LT. KOUNT) GO TO 20
      WRITE (7,114)  (HEDING(L), L=1,8)
      WRITE (7,104)
      LINES =0
   20 CONTINUE
C
C
   21 CONTINUE
      CALL PLOTZ
      IF (MORE .NE. 0) GO TO 2
C
C
C
C****************************  FORMATS  *********************************
  101 FORMAT (1H1, ' INPUT- WGT(LBS), DIAM(INS), GUN LGTH(INS),VMUZ(F/S)
     1 ,XMAX(INS), PMAX(INSQ) , CALTUN(CAL/TURN), IPOLAR(LBS-INSQ),
     2 MORE '  )
C
  102 FORMAT (    )
C
  104 FORMAT (/,68X,' AXIAL',21X,' SPIN ',/,5X,
     1    '  TRAVEL    PRESS     VEL        ACC       TH1D      TH2D
     2FORCEX(10)3  TORQUEX(10)3   FORCEX(10)3 ', /,
     3 6X,' (INS)    (LB/IN2)  (F/S)       (GS)      (RAD/S)  (RAD/S2)
     4   (LBS)       (LBS-INS)       (LBS)   ', /)
C
  105 FORMAT ( 7X,F6.2, 4X, F6.0, 3X,F5.0, 3X, F8.0, 2X, F8.0,2X,F9.0,
     1  5X, F7.2, 7X, F6.2, 6X, F7.2 )
C
  107 FORMAT( 1H1,/// ,  50X, ' I N P U T   D A T A',//,
     1 45X, ' WGT     DIAM    IPOLAR     VMUZ ', /,
     2 45X, '(LBS)    (INS)  (LB-INSQ)   (F/S)', /,
     3 45X,  F6.2, 2X, F5.2, 2X, F8.2, 3X, F5.0)
C
  108 FORMAT (  ////,  45X, ' LGTH     PMAX     XMAX     CAL/TURN ', /,
     1    45X,            '(INS)  (LB/INSQ) (INS) '  /,
     2    45X, F6.2, 3X, F6.0, 2X, F5.2, 5X, F3.0)
C
  109 FORMAT (/////, 50X, ' INITIAL  CALCULATIONS ', //,
     1  40X,   ' LE DUC  CONSTANTS ', //,
     2  40X,   '              A=', F8.2, ' (F/S)', //,
     3  40X,   '              B=', F6.2, ' (INS)' )
C
  111 FORMAT ( /// , 40X , ' MOMENT OF INERTIA ' //  ,
     1     47X ,           '      IPOLAR=', F7.2,' LB-INSQ' )
C
  112 FORMAT(8A6)
C
  114 FORMAT (  1H1 ,//  , 30X , 8A6 )
C
C****************************  FORMATS  *********************************
C
      END
```

```
PLOT2 =====

      SUBROUTINE PLOT2
C
C  THIS PLOTS PRESSURE, VELOCITY AND ACCELERATION (BOTH LINEAR AND ANGULAR
C        VS TRAVEL IN THE GUN TUBE
C
      COMMON /DAPLOT/ PRESS(402),VEL(402), ACC(402),TH1D(402), TH2D(402)
     1 , FORCE(402), TORQUE(402),X(402), EN(402)
C
C  ALL HORIZONTAL HEADINGS FOLLOW
C
      DIMENSION  IPRESV(8),  ILINVA(10), IANGVA(10), IFORTO( 8),ITRAV(3)
     1 ,ITORQ(6)
      DATA IPRESV /48H PRESSURE AND VELOCITY VS TRAVEL IN GUN TUBE    /
      DATA ILINVA /60H LINEAR VELOCITY AND ACCELERATION VS TRAVEL IN GUN
     1 TUBE       /
      DATA IANGVA /60H ANGULAR VELOCITY AND ACCELERATION VS TRAVEL IN GU
     1N TUBE      /
      DATA IFORTO  /48H AXIAL AND SPIN FORCES VS TRAVEL IN GUN TUBE    /
      DATA ITORQ   /36H TORQUE VS TRAVEL IN GUN TUBE        /
C
C
      DATA ITRAV /18H TRAVEL - (INS)    /
C
C  ALL VERTICAL LABELS FOLLOW
C
      DIMENSION YPRES(8),YVEL(8), YACC(12), YAXF(11), YTOR(6),YENF(10)
C
      DATA YPRES  /80,82,69,83,83,85,82,69/
      DATA YVEL /86,69,76,79,67,73,84,89/
      DATA YACC /65,67,67,69,76,69,82,65,84,73,79,78/
      DATA YAXF /65,88,73,65,76,32,70,79,82,67,69/
      DATA YTOR /84,79,82,81,85,69/
      DATA YENF /83,80,73,78,32,70,79,82,67,69/
C
      DIMENSION  PLBIN(10), VFS(5), VRDS(7), AFS2(6),ARDS2(8), FLBS(5),
     1 TOLBIN(8)
C
      DATA PLBIN /40,76,66,83,47,73,78,83,81,41/
      DATA VFS  /40,70,47,83,41/
      DATA VRDS /40,82,65,68,47,83,41/
      DATA AFS2 /40,71,38,83,41/
      DATA ARDS2 /40,82,65,68,47,83,50,41/
      DATA FLBS /40,76,66,83,41/
      DATA TOLBIN /40,76,66,45,73,78,83,41/
C
C
      K=0
      CALL INITT(30)
   10 CONTINUE
      CALL BINITT
      CALL SLIMX(180,870)
      K=K+1
      GO TO (1,2,3,4, 5) , K
C************************** GRAPH 1 ***************************************
C
    1 CONTINUE
C  PRESSURE AND VELOCITY VS TRAVEL
```

```
PLOT2 *****

      C
      C
            CALL CHECK([illegible])
            CALL DSPLAY([illegible])
            CALL [illegible]
            CALL [illegible]
            CALL [illegible]
            CALL [illegible]
            CALL DSPLAY([illegible])
            CALL [illegible]
      C
      C  HORIZONTAL TOP HEADING
      C
            CALL MOVABS([illegible])
            CALL [illegible]
            CALL [illegible]
      C
      C  LEFT VERTICAL LABEL
      C
            CALL MOVABS([illegible])
            CALL [illegible]
            CALL [illegible]
      C
      C  RIGHT VERTICAL LABEL
      C
            CALL MOVABS([illegible])
            CALL [illegible]
            CALL [illegible]
      C
      C  HORIZONTAL BOTTOM HEADING
      C
            CALL MOVABS([illegible])
            CALL [illegible]
      C
            GO TO 10
      C
      C************************************************************************
      C
      C
      C************************* GRAPH 2 *************************************
              2 CONTINUE
      C  ANGULAR VELOCITY AND ACCELERATION VS TRAVEL IN GUN TUBE
      C
      C
            CALL CHECK([illegible])
            CALL DSPLAY([illegible])
            CALL [illegible]
            CALL [illegible]
            CALL [illegible]
            CALL CHECK([illegible])
            CALL DSPLAY([illegible])
            CALL [illegible]
      C
      C  HORIZONTAL TOP HEADING
      C
            CALL MOVABS([illegible])
            CALL [illegible]
```

```
PLOT2  [illegible]

      CALL ACUTST(...,IANCVA)
C
C     LEFT VERTICAL LABEL
C
      CALL PLVALS(40, [illegible])
      CALL VLABEL(12,YACC)
      CALL ROTATE( [illegible] , ADUS2)
C
C     RIGHT VERTICAL LABEL
C
      CALL PLVAP[illegible]([illegible])
      CALL VLABEL( 4, YVEL)
      CALL ROTATE([illegible], 7, VRDS)
C
C     HORIZONTAL BOTTOM HEADING
C
      CALL PLVAHS (400 ,R0  )
      CALL ADLTST( 15, ITRAV)
      [illegible]
C**********************************************************************
C
C************************ GRAPH 3 *************************************
C     [illegible]
C     LINEAR VELOCITY AND ACCELERATION VS TRAVEL IN GUN TUBE
C
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
C
C     HORIZONTAL TOP HEADING
C
      [illegible]
      [illegible]
      [illegible]
C
C     LEFT VERTICAL LABEL
C
      [illegible]
      [illegible]
      [illegible]
C
C     RIGHT VERTICAL LABEL
C
      [illegible]
      [illegible]
      [illegible]
C
C
C     HORIZONTAL BOTTOM HEADING
C
      [illegible]
```

```
      CALL ACUTST(18,ITRAV)
      GO TO 15
C***************************************************************************
C
C
C************************** GRAPH 4 ****************************************
    4 CONTINUE
C  AXIAL AND SPIN FORCES VS TRAVEL
C
      CALL CHECK( X,FORCE)
      CALL DSFLAY(X,FORCE)
      CALL ARROW (X(40),FORCE(40),5,-5)
      CALL DINITY
      CALL YLOCRT(0)
C
C
      CALL CHECK (X, EN )
      CALL DSPLAY(X, EN )
      CALL ARROW (X(120),EN(120),-5,5)
C
C  HORIZONTAL TOP HEADING
C
      CALL MOVABS(200,760 )
      CALL AOUTST(48 , IFORTO)
      CALL CHRSIZ(2)
C
C  LEFT VERTICAL LABEL
C
      CALL MOVABS(30 ,500 )
      CALL VLABEL (11,YAXF)
      CALL NOTATE (0 ,200,  5,'FLPS)
C
C  RIGHT  VERTICAL LABEL
C
      CALL MOVABS( 980,500)
      CALL VLABEL (10 ,YENF )
      CALL NOTATE (950,230, 5, FLBS )
C
C  HORIZONTAL BOTTOM HEADING
C
      CALL MOVABS (400 ,50  )
      CALL AOUTST ( 18, ITRAV )
C
C***************************************************************************
C
      GO TO 15
C
C************************** GRAPH 5 ****************************************
C
C
C***************************************************************************
    5 CONTINUE
C  TORQUE VS TRAVEL IN GUN TUBE
      CALL CHECK (X,TORQUE)
      CALL DSPLAY (X,TORQUE)
C
C  HORIZONTAL TOP HEADING
```

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PLOTZ =====

```
C
      CALL MOVABS(300, 760 )
      CALL ACUTST(30, ITORG)
      CALL CHRSIZ(2)
C
C  LEFT VERTICAL LABEL
C
      CALL MOVABS(50, 500 )
      CALL VLABEL (6, YTCR)
      CALL NOTATE ( 0, 330, 8, TOLBIN)
C
C  HORIZONTAL BOTTOM HEADING
C
      CALL MOVABS (400 ,50  )
      CALL ACUTST (18, ITRAV )
C
C***************************************************************************
C
   15 CONTINUE
      CALL DCURSR (IC,IX,IY)
      CALL ERASE
      IF(IC .EQ. 83 )GO TO 30
      IF(K .NE. 5 )  GO TO 10
   30 CONTINUE
      CALL FINITT (0,400)
      RETURN
      END
```

ARROW =====

```
      SUBROUTINE ARROW(XMA,YMA,IX1,IX2)
C
C THIS SUBROUTINE ADDS ARROWS TO LINES ON GRAPHS
C   WHICH INDICATES SCALES
C
      XDR=15.
      IF(IX2 .LT. 0) XDR=-XDR
      CALL MOVEA(XMA,YMA)
      CALL DRAWR(XDR,0)
      CALL DRWREL(IX1,5)
      CALL DRWREL(0,-10)
      CALL DRWREL(IX2,5)
      RETURN
      END
```

NTAB/BCD =====

```
      N$TAB 31,2,1,1,1,1 6,7 1 5 0 29
      END
```

APPENDIX B. PROJECTILE MOTION AND LOADS VERSUS TRAVEL IN GUN TUBE

INPUT DATA

WGT (LBS)	DIAM (INS)	IPOLAR (LB-INSQ)	VMUZ (F/S)
96.00	6.00	495.00	2800.

LGTH (INS)	PMAX (LB/INSQ)	XMAX (INS)	CAL/TURN
200.00	53900.	22.50	20.

INITIAL CALCULATIONS

LE DUC CONSTANTS

A= 3430.00 (F/S)

B= 45.00 (INS)

TRAVEL (INS)	PRESS (LB/IN2)	VEL (F/S)	ACC (GS)	TH1D (RAD/S)	TH2D (RAD/S2)	AXIAL FORCEX(10)3 (LBS)	TORQUEX(10)3 (LBS-INS)	SPIN FORCEX(10)3 (LBS)
.00	0.	0.	0.	0.	0.	.00	.00	.00
1.00	7569.	75.	2027.	47.	41010.	194.59	52.54	17.73
2.00	14192.	146.	3901.	92.	76895.	364.97	98.51	33.24
3.00	19986.	214.	5352.	135.	108263.	513.80	138.72	46.81
4.00	25049.	280.	6708.	176.	135717.	643.98	173.86	58.66
5.00	29470.	343.	7892.	216.	159069.	757.03	204.55	69.02
6.00	33324.	404.	8924.	254.	180552.	856.72	231.30	78.04
7.00	36678.	462.	9822.	290.	198724.	942.94	254.56	85.90
8.00	39589.	518.	10602.	325.	214498.	1017.79	274.78	92.72
9.00	42109.	572.	11277.	359.	228161.	1082.58	292.27	98.62
10.00	44282.	624.	11959.	392.	239924.	1139.44	307.36	103.71
11.00	46147.	674.	12358.	423.	250029.	1186.39	320.30	108.08
12.00	47739.	722.	12784.	454.	258654.	1227.31	331.35	111.90
13.00	49088.	769.	13146.	483.	265963.	1261.99	340.71	114.96
14.00	50221.	814.	13449.	511.	272103.	1291.13	348.58	117.62
15.00	51163.	857.	13701.	539.	277204.	1315.33	355.11	119.82
16.00	51934.	900.	13908.	565.	281379.	1335.14	360.46	121.63
17.00	52552.	940.	14073.	591.	284732.	1351.05	364.76	123.08
18.00	53036.	980.	14203.	616.	287351.	1363.48	368.11	124.21
19.00	53399.	1018.	14300.	640.	289318.	1372.81	370.63	125.06
20.00	53655.	1055.	14369.	663.	290705.	1379.39	372.41	125.66
21.00	53815.	1091.	14412.	686.	291574.	1383.52	373.52	126.03
22.00	53891.	1126.	14432.	708.	291985.	1385.47	374.05	126.21
22.50	53900.	1143.	14434.	718.	292034.	1385.70	374.11	126.23
3.00	53891.	1160.	14432.	729.	291987.	1385.47	374.05	126.21
24.00	53825.	1193.	14414.	750.	291626.	1383.76	373.59	126.06
25.00	53699.	1225.	14380.	770.	290943.	1380.52	372.71	125.76
26.00	53520.	1256.	14333.	789.	289975.	1375.93	371.47	125.34
27.00	53295.	1286.	14272.	808.	288754.	1370.14	369.91	124.82
28.00	53028.	1316.	14201.	827.	287310.	1363.29	368.06	124.19
29.00	52725.	1344.	14120.	845.	285070.	1355.50	365.96	123.48
30.00	52391.	1372.	14030.	862.	283957.	1346.90	363.64	122.70
31.00	52028.	1399.	13933.	879.	281892.	1337.58	361.12	121.85
32.00	51641.	1425.	13829.	896.	279795.	1327.62	358.43	120.94
33.00	51233.	1451.	13720.	912.	277582.	1317.13	355.60	119.99
34.00	50806.	1476.	13606.	928.	275270.	1306.16	352.64	118.99
35.00	50363.	1501.	13487.	943.	272873.	1294.76	349.57	117.95
36.00	49907.	1524.	13365.	958.	270402.	1283.05	346.40	116.88
37.00	49440.	1548.	13240.	972.	267869.	1271.04	343.15	115.79

TRAVEL (INS)	PRESS (LB/IN2)	VEL (F/S)	ACC (GS)	TH1D (RAD/S)	TH2D (RAD/S2)	AXIAL FORCEX(10)3 (LBS)	TORQUEX(10)3 (LBS-INS)	SPIN FORCEX(10)3 (LBS)
38.00	48963.	1570.	13112.	987.	265204.	1258.77	339.84	114.67
39.00	48478.	1592.	12982.	1001.	262057.	1246.30	336.48	113.53
40.00	47987.	1614.	12851.	1014.	259995.	1233.67	333.07	112.38
41.00	47490.	1635.	12718.	1027.	257306.	1220.92	329.62	111.22
42.00	46990.	1656.	12584.	1040.	254597.	1208.06	326.15	110.05
43.00	46488.	1676.	12449.	1053.	251873.	1195.14	322.66	108.87
44.00	45983.	1696.	12314.	1065.	249141.	1182.17	319.16	107.69
45.00	45478.	1715.	12179.	1078.	246403.	1169.18	315.66	106.51
46.00	44973.	1734.	12044.	1089.	243666.	1156.19	312.15	105.33
47.00	44468.	1752.	11909.	1101.	240933.	1143.23	308.65	104.14
48.00	43965.	1770.	11774.	1112.	238207.	1130.29	305.16	102.97
49.00	43464.	1788.	11640.	1123.	235491.	1117.40	301.66	101.79
50.00	42965.	1805.	11506.	1134.	232788.	1104.58	298.21	100.62
51.00	42469.	1822.	11373.	1145.	230101.	1091.83	294.77	99.46
52.00	41976.	1839.	11241.	1155.	227431.	1079.16	291.35	98.31
53.00	41487.	1855.	11110.	1166.	224781.	1066.58	287.96	97.16
54.00	41002.	1871.	10980.	1176.	222152.	1054.11	284.59	96.03
55.00	40521.	1886.	10851.	1185.	219546.	1041.74	281.25	94.90
56.00	40044.	1902.	10724.	1195.	216963.	1029.49	277.94	93.78
57.00	39572.	1917.	10597.	1204.	214406.	1017.35	274.67	92.68
58.00	39105.	1931.	10472.	1214.	211874.	1005.34	271.42	91.58
59.00	38643.	1946.	10349.	1223.	209370.	993.46	268.21	90.50
60.00	38186.	1960.	10226.	1232.	206893.	981.70	265.04	89.43
61.00	37734.	1974.	10105.	1240.	204444.	970.08	261.90	88.37
62.00	37287.	1987.	9985.	1249.	202024.	958.60	258.80	87.33
63.00	36846.	2001.	9867.	1257.	199632.	947.25	255.74	86.29
64.00	36410.	2014.	9750.	1265.	197271.	936.05	252.71	85.27
65.00	35979.	2027.	9635.	1273.	194938.	924.98	249.73	84.26
66.00	35554.	2039.	9521.	1281.	192636.	914.06	246.78	83.27
67.00	35135.	2052.	9409.	1289.	190363.	903.27	243.87	82.29
68.00	34721.	2064.	9298.	1297.	188120.	892.63	240.99	81.32
69.00	34312.	2076.	9189.	1304.	185907.	882.13	238.16	80.36
70.00	33910.	2088.	9081.	1312.	183724.	871.77	235.36	79.42
71.00	33512.	2099.	8975.	1319.	181571.	861.55	232.60	78.48
72.00	33120.	2111.	8870.	1326.	179447.	851.48	229.88	77.57
73.00	32734.	2122.	8766.	1333.	177353.	841.54	227.20	76.66
74.00	32353.	2133.	8664.	1340.	175288.	831.74	224.55	75.77
75.00	31977.	2144.	8563.	1347.	173252.	822.08	221.95	74.89
76.00	31606.	2154.	8464.	1354.	171246.	812.56	219.38	74.02
77.00	31241.	2165.	8366.	1360.	169267.	803.17	216.84	73.17
78.00	30881.	2175.	8270.	1367.	167317.	793.92	214.34	72.32
79.00	30527.	2185.	8175.	1373.	165396.	784.80	211.88	71.49
80.00	30177.	2195.	8081.	1379.	163502.	775.81	209.45	70.67
81.00	29833.	2205.	7989.	1385.	161635.	766.96	207.06	69.87
82.00	29493.	2215.	7898.	1392.	159796.	758.23	204.71	69.07
83.00	29159.	2224.	7809.	1397.	157983.	749.63	202.38	68.29
84.00	28829.	2233.	7720.	1403.	156197.	741.15	200.10	67.52
85.00	28504.	2243.	7633.	1409.	154437.	732.80	197.84	66.76
86.00	28184.	2252.	7548.	1415.	152703.	724.57	195.62	66.01
87.00	27869.	2261.	7463.	1420.	150994.	716.46	193.43	65.27
88.00	27558.	2269.	7380.	1426.	149310.	708.48	191.27	64.54
89.00	27252.	2278.	7298.	1431.	147651.	700.60	189.15	63.82
90.00	26950.	2287.	7217.	1437.	146017.	692.85	187.06	63.12
91.00	26653.	2295.	7138.	1442.	144406.	685.21	184.99	62.42
92.00	26360.	2303.	7059.	1447.	142820.	677.68	182.96	61.73
93.00	26071.	2312.	6982.	1452.	141256.	670.26	180.96	61.06
94.00	25787.	2320.	6906.	1457.	139716.	662.95	178.98	60.39
95.00	25507.	2327.	6831.	1462.	138198.	655.75	177.04	59.74
96.00	25231.	2335.	6757.	1467.	136702.	648.65	175.12	59.09
97.00	24959.	2343.	6684.	1472.	135229.	641.66	173.24	58.45
98.00	24691.	2351.	6612.	1477.	133776.	634.77	171.38	57.83
99.00	24427.	2358.	6541.	1482.	132346.	627.98	169.54	57.21
100.00	24166.	2366.	6472.	1486.	130936.	621.29	167.74	56.60
101.00	23910.	2373.	6403.	1491.	129546.	614.70	165.96	56.00
102.00	23657.	2380.	6335.	1495.	128177.	608.20	164.20	55.41
103.00	23408.	2387.	6269.	1500.	126828.	601.80	162.47	54.82
104.00	23163.	2394.	6203.	1504.	125498.	595.49	160.77	54.25
105.00	22921.	2401.	6138.	1509.	124187.	589.27	159.09	53.68
106.00	22683.	2408.	6074.	1513.	122896.	583.14	157.44	53.12
107.00	22448.	2415.	6011.	1517.	121623.	577.10	155.81	52.57

TRAVEL (INS)	PRESS (LB/IN2)	VEL (F/S)	ACC (GS)	TH1D (RAD/S)	TH2D (RAD/S2)	AXIAL FORCEX(10)3 (LBS)	TORQUEX(10)3 (LBS-INS)	SPIN FORCEX(10)3 (LBS)
108.00	22216.	2421.	5949.	1521.	120368.	571.15	154.20	52.03
109.00	21988.	2428.	5888.	1525.	119131.	565.28	152.61	51.50
110.00	21763.	2434.	5828.	1529.	117912.	559.49	151.05	50.97
111.00	21541.	2441.	5769.	1533.	116711.	553.79	149.51	50.45
112.00	21322.	2447.	5710.	1537.	115526.	548.17	148.00	49.94
113.00	21107.	2453.	5652.	1541.	114359.	542.63	146.50	49.43
114.00	20894.	2459.	5596.	1545.	113208.	537.17	145.03	48.93
115.00	20685.	2465.	5539.	1549.	112073.	531.78	143.57	48.44
116.00	20478.	2471.	5484.	1553.	110954.	526.47	142.14	47.96
117.00	20275.	2477.	5430.	1556.	109851.	521.24	140.72	47.48
118.00	20074.	2483.	5376.	1560.	108763.	516.08	139.33	47.01
119.00	19876.	2489.	5323.	1564.	107690.	510.99	137.96	46.55
120.00	19681.	2495.	5271.	1567.	106633.	505.97	136.60	46.09
121.00	19489.	2500.	5219.	1571.	105590.	501.02	135.27	45.64
122.00	19299.	2506.	5168.	1574.	104562.	496.14	133.95	45.20
123.00	19112.	2511.	5118.	1578.	103547.	491.33	132.65	44.76
124.00	18927.	2517.	5069.	1581.	102547.	486.59	131.37	44.33
125.00	18745.	2522.	5020.	1585.	101561.	481.90	130.10	43.90
126.00	18565.	2527.	4972.	1588.	100588.	477.29	128.86	43.48
127.00	18388.	2533.	4924.	1591.	99628.	472.73	127.63	43.06
128.00	18213.	2538.	4878.	1595.	98681.	468.24	126.42	42.66
129.00	18041.	2543.	4831.	1598.	97747.	463.81	125.22	42.25
130.00	17871.	2548.	4786.	1601.	96826.	459.44	124.04	41.85
131.00	17703.	2553.	4741.	1604.	95917.	455.12	122.87	41.46
132.00	17538.	2558.	4697.	1607.	95020.	450.87	121.73	41.07
133.00	17374.	2563.	4653.	1610.	94136.	446.67	120.59	40.69
134.00	17213.	2568.	4610.	1613.	93263.	442.53	119.47	40.31
135.00	17054.	2572.	4567.	1616.	92401.	438.44	118.37	39.94
136.00	16897.	2577.	4525.	1619.	91551.	434.41	117.28	39.57
137.00	16743.	2582.	4484.	1622.	90713.	430.43	116.21	39.21
138.00	16590.	2587.	4443.	1625.	89885.	426.50	115.15	38.85
139.00	16439.	2591.	4402.	1628.	89068.	422.63	114.10	38.50
140.00	16290.	2596.	4363.	1631.	88262.	418.80	113.07	38.15
141.00	16144.	2600.	4323.	1634.	87467.	415.03	112.05	37.81
142.00	15999.	2605.	4284.	1637.	86681.	411.30	111.04	37.47
143.00	15856.	2609.	4246.	1639.	85906.	407.62	110.05	37.13
144.00	15714.	2613.	4208.	1642.	85141.	403.99	109.07	36.80
145.00	15575.	2618.	4171.	1645.	84386.	400.41	108.10	36.48
146.00	15437.	2622.	4134.	1647.	83640.	396.87	107.15	36.15
147.00	15301.	2626.	4098.	1650.	82904.	393.38	106.20	35.84
148.00	15167.	2630.	4062.	1653.	82177.	389.93	105.27	35.52
149.00	15035.	2634.	4026.	1655.	81460.	386.53	104.35	35.21
150.00	14904.	2638.	3991.	1658.	80751.	383.16	103.45	34.91
151.00	14775.	2642.	3957.	1660.	80052.	379.84	102.55	34.60
152.00	14647.	2646.	3923.	1663.	79361.	376.57	101.67	34.30
153.00	14522.	2650.	3889.	1665.	78679.	373.33	100.79	34.01
154.00	14397.	2654.	3856.	1668.	78005.	370.13	99.93	33.72
155.00	14274.	2658.	3823.	1670.	77340.	366.98	99.08	33.43
156.00	14153.	2662.	3790.	1673.	76683.	363.86	98.24	33.15
157.00	14033.	2666.	3758.	1675.	76034.	360.78	97.40	32.87
158.00	13915.	2670.	3726.	1677.	75393.	357.74	96.58	32.59
159.00	13798.	2673.	3695.	1680.	74760.	354.73	95.77	32.32
160.00	13683.	2677.	3664.	1682.	74134.	351.77	94.97	32.04
161.00	13569.	2681.	3634.	1684.	73517.	348.84	94.18	31.78
162.00	13456.	2684.	3604.	1687.	72906.	345.94	93.40	31.51
163.00	13345.	2688.	3574.	1689.	72304.	343.08	92.62	31.25
164.00	13235.	2691.	3544.	1691.	71708.	340.25	91.86	31.00
165.00	13126.	2695.	3515.	1693.	71119.	337.46	91.11	30.74
166.00	13019.	2698.	3486.	1696.	70538.	334.70	90.36	30.49
167.00	12913.	2702.	3458.	1698.	69963.	331.98	89.63	30.24
168.00	12808.	2705.	3430.	1700.	69396.	329.28	88.90	30.00
169.00	12705.	2709.	3402.	1702.	68835.	326.62	88.18	29.75
170.00	12602.	2712.	3375.	1704.	68280.	323.99	87.47	29.51
171.00	12501.	2715.	3348.	1706.	67732.	321.39	86.77	29.28
172.00	12401.	2719.	3321.	1708.	67191.	318.82	86.08	29.04
173.00	12303.	2722.	3295.	1710.	66656.	316.28	85.39	28.81
174.00	12205.	2725.	3268.	1712.	66127.	313.77	84.71	28.58
175.00	12108.	2728.	3243.	1714.	65604.	311.29	84.04	28.36
176.00	12013.	2732.	3217.	1716.	65088.	308.84	83.38	28.13
177.00	11919.	2735.	3192.	1718.	64577.	306.42	82.73	27.91

TRAVEL (INS)	PRESS (LB/IN2)	VEL (F/S)	ACC (GS)	THIC (RAD/S)	THID (RAD/S2)	AXIAL FORCEX(10)3 (LBS)	TORQUEX(10)3 (LBS-INS)	SPIN FORCEX(10)3 (LBS)
178.00	11826.	2738.	3167.	1720.	64072.	304.02	82.08	27.70
179.00	11733.	2741.	3142.	1722.	63573.	301.05	81.44	27.48
180.00	11642.	2744.	3118.	1724.	63079.	299.31	80.81	27.27
181.00	11552.	2747.	3094.	1726.	62591.	297.00	80.18	27.06
182.00	11463.	2750.	3070.	1728.	62109.	294.71	79.57	26.85
183.00	11375.	2753.	3046.	1730.	61632.	292.44	78.95	26.64
184.00	11288.	2756.	3023.	1732.	61161.	290.21	78.35	26.44
185.00	11202.	2759.	3000.	1733.	60695.	288.00	77.75	26.24
186.00	11117.	2762.	2977.	1735.	60234.	285.81	77.16	26.04
187.00	11033.	2765.	2955.	1737.	59778.	283.64	76.58	25.84
188.00	10950.	2768.	2932.	1739.	59327.	281.51	76.00	25.64
189.00	10868.	2770.	2910.	1741.	58881.	273.39	75.43	25.45
190.00	10786.	2773.	2889.	1742.	58440.	277.30	74.87	25.26
191.00	10706.	2776.	2867.	1744.	58004.	275.23	74.31	25.07
192.00	10626.	2779.	2846.	1746.	57573.	273.18	73.75	24.89
193.00	10547.	2781.	2825.	1746.	57146.	271.16	73.21	24.70
194.00	10469.	2784.	2804.	1749.	56724.	269.16	72.67	24.52
195.00	10392.	2787.	2783.	1751.	56307.	267.18	72.13	24.34
196.00	10316.	2790.	2763.	1753.	55894.	265.22	71.60	24.16
197.00	10241.	2792.	2742.	1754.	55486.	263.28	71.08	23.98
198.00	10166.	2795.	2723.	1756.	55082.	261.36	70.56	23.81
199.00	10093.	2797.	2703.	1758.	54062.	259.47	70.05	23.64
200.00	10020.	2300.	2683.	1759.	54287.	257.59	69.54	23.47

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IN GUN TUBE - Robert A. Muldoon

Technical Report AMMRC TR 77-9, March 1977,
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Using a Le Duc representation of the pressure-travel curve, the linear and angular velocity and acceleration of the projectile are determined as a function of travel within the gun tube. With the motion parameters established, the set-back force, spin force, and spin moment are calculated as a function of travel within the gun tube. Based on these equations a computer program is developed which outputs, both graphically and in tabular form, the force, moment, and motion parameters for the projectile during the interior ballistic regime. The program requires the input of the projectile weight, diameter, polar moment of inertia, muzzle velocity, gun length, maximum pressure, location of maximum pressure, and the rifling twist. A FORTRAN listing of the program is given and the program illustrated by a sample problem.

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